

## §6. Temperature Differences in Parallel Cooling Paths for the Supporting Structure of the LHD

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A supporting structure for superconducting coils of the LHD is a very large torus-shaped shell. Its weight is about 400 ton including the rib structure for the poloidal coils. It is cooled by gaseous helium during cool-down and two-phase helium in a steady state. In order to reduce the possibility of helium leakage, seamless pipes were adopted. These were attached on the outer surface by metal cleats mechanically and by epoxy resin of STYCAST 2580FT thermally. The inner diameter of 17.5 mm was selected for workability. The distance of the pipes is less than 400 mm, and the total length exceeds 2.3 km. Therefore, parallel cooling paths are indispensable to attain sufficient mass flow. Considering the periodicity of 10, the number of parallel paths was determined to be 80 for the cool-down. 8 types of cooling pipes are arranged radially, as shown in Fig. 1. The inlets are located at the inside. In the two-phase helium cooling, two lower and two upper paths come in a series by closing the return from two outlet-headers and one of three inlet-headers in order to avoid the effect of gravity. The number of parallel paths is reduced to 20.

During cool-down, the temperature of supplied helium gas was controlled to keep the temperature differences in the coils and the structure less than 50 K. Figure 2 shows the change of temperature differences among the route (2) pipes during the 4th cool-down. Each sensor is inserted in a copper block that is attached on the pipe with a steel band. The differences were enlarged to about 7 K at the early stage of cool-down and saturated. They are considered to be caused mainly by the difference of friction factors of the cooling pipes due to the tolerance of inner diameters or bending radii. Since the routes of pipes vary in length from 19 to 29 m, the maximum temperature difference in 80 paths was enlarged to 20 K. It can be lessened by adjusting the control valves of the three inlet headers.

In steady state cooling, the temperature differences are reduced. Although the oscillations of temperatures of 0.1-0.5 K are observed they do not induce harmful instability. In order to investigate the mechanism, the supply of the cryogen was stopped for two hours and resumed. The total flow rate was about 50 g/s. The temperatures of the route (2) pipes are shown in Fig. 3. The increase of 0.5 K during the discharge is caused by the effect of magnetic field on the PtCo sensors. The temperature rises of the pipes were about 2 K, while those of the structure were about 0.5 K. The pipes were heated locally by the sensors. After the supply was resumed, the lowest temperature of each oscillation was returned to the former values within 7 to 9 minutes. It shows that liquid is sometimes supplied to all the pipes and that the real temperatures of all the pipe are closed to 4.4 K. The oscillations of temperatures will be caused by density waves. Under the sufficient mass flow, this cooling system with many parallel paths is stable even for two-phase helium. The effect of flow rate will be investigated in the next campaign.

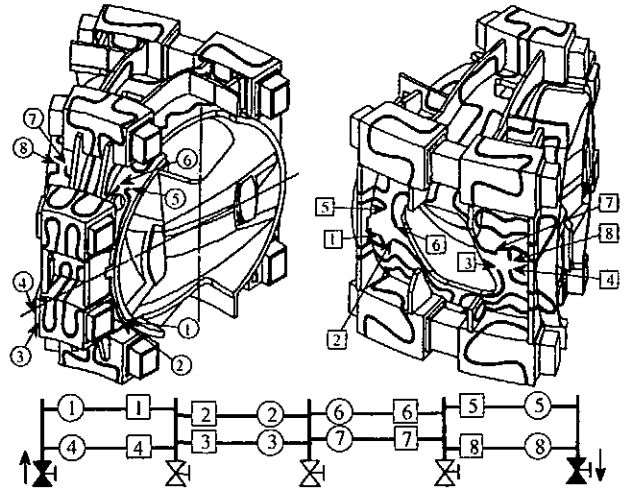


Fig. 1. Layout of cooling pipes for the supporting structure.

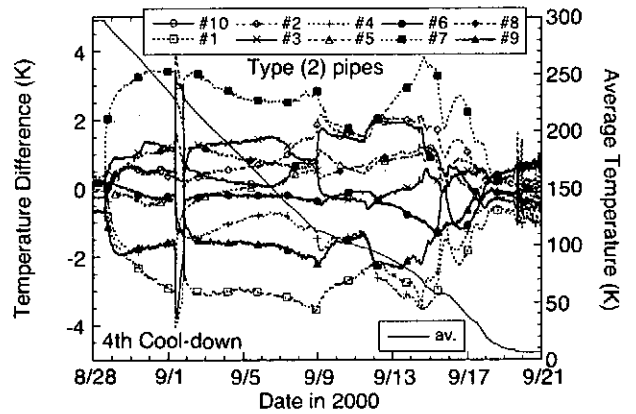


Fig. 2. Temperature difference among the ten cooling pipes of route (2) during the 4th cool-down.

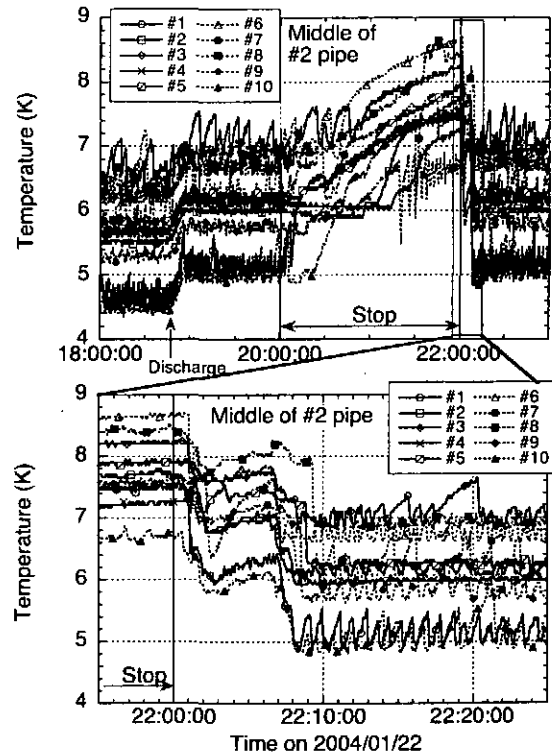


Fig. 3. Temperatures of the type (2) cooling pipes during a stop of the cryogen for two hours